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Risk factors influencing fracture characteristics in postoperative periprosthetic femoral fractures around cemented stems in total hip arthroplasty

A MULTICENTRE OBSERVATIONAL COHORT STUDY ON 584 FRACTURES

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Aims

This study evaluates risk factors influencing fracture characteristics for postoperative periprosthetic femoral fractures (PFFs) around cemented stems in total hip arthroplasty.

Methods

Data were collected for PFF patients admitted to eight UK centres between 25 May 2006 and 1 March 2020. Radiographs were assessed for Unified Classification System (UCS) grade and AO/OTA type. Statistical comparisons investigated relationships by age, gender, and stem fixation philosophy (polished taper-slip (PTS) vs composite beam (CB)). The effect of multiple variables was estimated using multinomial logistic regression to estimate odds ratios (ORs) with 95% confidence intervals (CIs). Surgical treatment (revision vs fixation) was compared by UCS grade and AO/OTA type.

Results

A total of 584 cases were included. Median age was 79.1 years (interquartile range 72.0 to 86.0), 312 (53.6%) patients were female, and 495 (85.1%) stems were PTS. The commonest UCS grade was type B1 (278, 47.6%). The most common AO/OTA type was spiral (352, 60.3%). Metaphyseal split fractures occurred only with PTS stems with an incidence of 10.1%. Male sex was associated with a five-fold reduction in odds of a type C fracture (OR 0.22 (95% CI 0.12 to 0.41); $p < 0.001$) compared to a type B fracture. CB stems were associated with significantly increased odds of transverse fracture (OR 9.51 (95% CI 3.72 to 24.34); $p < 0.001$) and wedge fracture (OR 3.72 (95% CI 1.16 to 11.95); $p = 0.027$) compared to PTS stems. Both UCS grade and AO/OTA type differed significantly ($p < 0.001$ and $p = 0.001$, respectively) between the revision and fixation groups but a similar proportion of B1 fractures underwent revision compared to fixation (45.3% vs 50.6%).

Conclusion

The commonest fracture types are B1 and spiral fractures. PTS stems are exclusively associated with metaphyseal split fractures, but their incidence is low. Males have lower odds of UCS grade C fractures compared to females. CB stems have higher odds of bending type fractures (transverse and wedge) compared to PTS stems. There is considerable variation in practice when treating B1 fractures around cemented stems.

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Introduction

Cemented total hip arthroplasty (THA) provides excellent long-term outcomes and is proven to be cost-effective.[1-4] Polished taper-slip (PTS) stems are now the commonest cemented femoral stem having overtaken traditional composite beam (CB) stems. They consistently demonstrate successful results,[5,6] but recent reports have indicated an increased risk of postoperative periprosthetic femoral fracture (PFF) compared to CB stems.[7–13] PFFs usually require complex surgery, which is burdened with unacceptably high rates of morbidity, complication, and healthcare costs.[14,15]

Patient- and implant-related risk factors for PFF around cemented stems have been demonstrated in large registry-based cohort studies but little is known about fracture characteristics.[7,9,11,16] Fenelon et al[17] analyzed 138 PFFs and found a higher proportion of comminuted fractures with cemented stems compared to cementless stems, but this study was limited by its sample size and fracture classification protocol. PFFs are graded using the Unified Classification System (UCS) based on fracture location, stem stability, and femoral bone stock.[18] They can also be described using the AO/OTA system based on fracture morphology.[19] An additional fracture type specific to PFFs around PTS stems is the metaphyseal split (or log-splitter) fracture where there is bone and cement comminution with cement mantle fracture and an intact bone-cement interface.[20] Simple fractures can be treated successfully with internal fixation and have more predictable outcomes than revision surgery, which is commonly indicated for comminuted fractures, transverse fractures, or those that occur around a loose stem or with severe bone loss.[21–24] A more detailed understanding of fracture patterns around cemented stems and associated risk factors may help guide preventative and therapeutic strategies.[25]

This study aims to describe fracture characteristics in patients with a PFF around a primary THA with a cemented stem. In addition, we aim to determine patient- and implant-related risk factors for UCS grade and AO/OTA type and the effect of fracture type on choice of surgical treatment.

Methods

A multicentre observational cohort study was performed. This study was approved by our local Research Ethics Committee (MREC 19-005 Amd1). Data were collected for PFF patients admitted to eight UK centres between 25 May 2006 and 1 March 2020. Cases were identified using pre-existing databases of consecutive PFFs admitted to each centre. Demographic data and radiographs were deidentified and collated for analysis. Excluded cases were hemiarthroplasty patients, interprosthetic fractures occurring between a THA stem and an ipsilateral distal femoral implant, intraoperative fractures, and stem brands with fewer than 20 cases in the whole dataset.

Demographic data included age at time of PFF (years), sex, laterality, stem fixation (PTS vs CB), and stem brand. Patients were divided into age groups representing younger patients (under 60 years), typical patients (60 to 80 years), and older patients (over 80 years). PTS stem brands in the series were Exeter (Stryker, USA), CPT (Zimmer Biomet, USA), C-stem classic, and C-stem AMT (both Depuy Synthes, USA) stems. CB stems were all Charnley (Depuy Synthes) stems. Fracture variables assessed via radiographs were UCS grade[18] and AO/OTA fracture type[19] for all UCS grade B and C fractures. UCS grades were AG (greater trochanter fracture), AL (lesser trochanter fracture), B1 (fracture around a stable stem), B2 (fracture around a loose stem, B3 (fracture around a loose stem with loss of bone stock to the extent that it is no longer capable of supporting a standard revision stem), and C (well below the stem tip).[18] A loose CB stem was defined by radiolucency at either the cement-bone interface or stem-cement interface whereas a loose PTS stem was defined by radiolucency at the cement-bone interface or if stable anatomical reduction was unlikely due to a comminuted or irreducible cement mantle.[22,26] AO/OTA types were transverse (< 30° to a line perpendicular to the long bone axis), oblique (≥ 30° to a line perpendicular to the long bone axis), spiral (fracture line rotating around long bone axis), and wedge (bending fracture creating a single or multiple wedge fragments).[19]

Table I. Baseline demographic data of all study patients (n = 584).

Characteristic	Result
Median age, yrs (IQR)	79.07 (71.98 to 86.00)
Sex, n (%)	
Female	314 (53.8)
Male	270 (46.2)
Side, n (%)	
Left	280 (47.9)
Right	304 (52.1)
Stem brand, n (%)	
C stem AMT	20 (3.4)
C stem classic	39 (6.7)
Charnley	87 (14.9)
CPT	201 (34.4)
Exeter	237 (40.6)
Stem fixation, n (%)	
CB	87 (14.9)
PTS	497 (85.1)
UCS, n (%)	
AG	18 (3.1)
AL	7 (1.2)
B1	278 (47.6)
B2	152 (26.0)
B3	52 (8.9)
C	77 (13.2)
AO/OTA type, n (%)	
Oblique	85 (14.6)
Transverse	48 (8.2)
Wedge	24 (4.1)
Spiral	352 (60.3)
Metaphyseal split	50 (8.6)
N/A	25 (4.3)

CB, composite beam; IQR, interquartile range; N/A, not applicable; OTA, Orthopaedic Trauma Association; PTS, polished taper-slip; UCS, Unified Classification System.

Table II. Comparison of fractures occurring in young, typical age, and older patients.

Variable	< 60 yrs	60 to 80 yrs	> 80 yrs	p-value*
Total, n	41	262	281	
Sex, n (%)				0.687
Female	21 (51.2)	146 (55.7)	147 (52.3)	
Male	20 (48.8)	116 (44.3)	134 (47.7)	
Stem brand, n (%)				0.319
C stem AMT	3 (7.3)	5 (1.9)	12 (4.3)	
C stem classic	3 (7.3)	20 (7.6)	16 (5.7)	
Charnley	4 (9.8)	34 (13.0)	49 (17.4)	
CPT	14 (34.1)	99 (37.8)	88 (31.3)	
Exeter	17 (41.5)	104 (39.7)	116 (41.3)	
Stem fixation, n (%)				0.218
CB	4 (9.8)	34 (13.0)	49 (17.4)	
PTS	37 (90.2)	228 (87.0)	232 (82.6)	
UCS grade, n (%)				0.385
AG	0 (0.0)	4 (1.5)	3 (1.1)	
AL	1 (2.4)	9 (3.4)	8 (2.8)	
B1	22 (53.7)	125 (47.7)	131 (46.6)	
B2	10 (24.4)	76 (29.0)	66 (23.5)	
B3	6 (14.6)	19 (7.3)	27 (9.6)	
C	2 (4.9)	29 (11.1)	46 (16.4)	
AO/OTA type, n (%)				0.196
Oblique	5 (12.2)	38 (14.5)	42 (14.9)	
Transverse	4 (9.8)	19 (7.3)	25 (8.9)	
Wedge	0 (0.0)	16 (6.1)	8 (2.8)	
Spiral	23 (56.1)	158 (60.3)	171 (60.9)	
Metaphyseal split	8 (19.5)	18 (6.9)	24 (8.5)	
N/A	1 (2.4)	13 (5.0)	11 (3.9)	

*Chi-squared test.
CB, composite beam; IQR, interquartile range; N/A, not applicable; OTA, Orthopaedic Trauma Association; PTS, polished taper-slip; UCS, Unified Classification System.

An additional category was specified for metaphyseal split fractures with comminution of bone and cement but an intact bone-cement interface.[20] Radiographs were assessed by two arthroplasty-trained investigators (SJ, JNL) and in any cases where there was uncertainty in classification, the final decision was settled through discussion. Surgical treatment data were collected and compared (fixation vs revision). Fixation was defined as the use of any fracture fixation device to stabilize the fracture without THA implant exchange. Revision was defined as removal, exchange, or modification of any component of the primary THA construct with or without an additional fixation device.

Statistical analysis. The primary outcome variables were UCS grade and AO/OTA type and the measured predictor variables were age, sex, and stem fixation philosophy. Data were tested for normality using the Shapiro-Wilks test. Normally distributed continuous variables were summarized as mean values with standard deviations (SDs) and non-normally distributed variables as medians with interquartile ranges (IQRs). Comparisons of fracture patterns were performed to investigate relationships by age, sex, and stem fixation philosophy. Comparisons between continuous variables with a normal distribution were performed with a independent-samples *t*-test and a non-normal distribution with a Mann-Whitney U test. Comparison of ordinal and nominal variables were performed with chi-squared tests.

Regression analysis was performed to adjust for heterogeneity between groups and possible confounding factors. The effect of multiple variables on UCS grade and AO/OTA fracture type was estimated separately. As no metaphyseal split fractures were seen with CB stems, these were removed from the model and analyzed descriptively to eliminate the effect of sparse data bias.[27] Multinomial logistic regression models were used to estimate odds ratios (ORs) with 95% confidence intervals (CIs) compared to a reference value. Statistical significance was set to $p < 0.05$.

Results

In total, 584 cases of PFF following primary THA with cemented stems were included in the analysis (Table I). Median age was 79.1 years (IQR 72.0 to 86.0) and 314 (53.8%) patients were female. PTS stems accounted for 497 (85.1%) in the series. Males and females were of a similar age (p = 0.690, Mann-Whitney U test, Table II) but CB stems were more common in females compared to males (18.8% vs 10.4%; p = 0.005, chi-squared test, Table III). Patients with CB stems were also older at the time of fracture (83.0 years vs 79.0 years; p = 0.003, Mann-Whitney U test, Table IV) than patients with PTS stems. The commonest UCS grade was grade B (482, 82.5%) of which grade B1 (278, 47.6%) was the most prevalent. The commonest AO/OTA fracture type was spiral (352, 60.3%) and the least common was wedge (24, 4.1%). Metaphyseal split fractures accounted for only 50 (8.6%) cases overall.

UCS grade. UCS grade did not change significantly between age groups (p overall = 0.390, chi-squared test, Table II). A significant difference was seen in UCS grade between males and females (p overall < 0.001, chi-squared test, Table III). Females had a greater proportion of C fractures (20.1% vs 5.2%) but fewer B2 fractures (20.1% vs 33.0%) than males (p < 0.001, chi-squared test). UCS grade differed between stem fixation philosophy groups (p overall = 0.003, chi-squared test, Table IV). Patients with CB stems had a greater proportion of AG (3.4% vs 0.8%), B3 (13.8% vs 8.0%), and C fractures (19.5% vs 12.1%) but fewer AL (0.0% vs 3.6%) and B1 fractures (34.5% vs 49.9%) compared to PTS stems (p = 0.003, chi-squared test).

AO/OTA fracture type. AO/OTA fracture type did not differ between age groups (p overall = 0.200, chi-squared test, Table II). A significant difference was seen in AO/OTA

Table III. Comparison of fractures between females and males.

Variable	Female	Male	p-value
Total, n	314	270	
Median age, yrs (IQR)	79.00 (72.00 to 86.00)	80.00 (71.00 to 86.12)	0.692*
Stem brand, n (%)			†0.001
C stem AMT	10 (3.2)	10 (3.7)	
C stem classic	23 (7.3)	16 (5.9)	
Charnley	59 (18.8)	28 (10.4)	
CPT	117 (37.3)	84 (31.1)	
Exeter	105 (33.4)	132 (48.9)	
Stem fixation, n (%)			†0.005
CB	59 (18.8)	28 (10.4)	
PTS	255 (81.2)	242 (89.6)	
UCS grade, n (%)			< 0.001†
AG	4 (1.3)	3 (1.1)	
AL	9 (2.9)	9 (3.3)	
B1	149 (47.5)	129 (47.8)	
B2	63 (20.1)	89 (33.0)	
B3	26 (8.3)	26 (9.6)	
C	63 (20.1)	14 (5.2)	
AO/OTA type, n (%)			†0.009
Oblique	39 (12.4)	46 (17.0)	
Transverse	31 (9.9)	17 (6.3)	
Wedge	17 (5.4)	7 (2.6)	
Spiral	197 (62.7)	155 (57.4)	
Metaphyseal split	17 (5.4)	33 (12.2)	
N/A	13 (4.1)	12 (4.4)	

*Mann-Whitney U test.
†Chi-squared test.
CB, composite beam; IQR, interquartile range; N/A, not applicable; OTA, Orthopaedic Trauma Association; PTS, polished taper-slip; UCS, Unified Classification System

Table IV. Comparison of fractures by stem fixation philosophy.

Variable	CB stems	PTS stems	p-value*
Total, n	87	497	
Sex, n (%)			0.005
Female	59 (67.8)	255 (51.3)	
Male	28 (32.2)	242 (48.7)	
Median age, yrs (IQR)	83.00 (77.00 to 88.00)	79.00 (71.00 to 86.00)	0.003
Stem brand, n (%)			< 0.001
C stem AMT	0 (0.0)	20 (4.0)	
C stem classic	0 (0.0)	39 (7.8)	
Charnley	87 (100.0)	0 (0.0)	
CPT	0 (0.0)	201 (40.4)	
Exeter	0 (0.0)	237 (47.7)	
UCS grade, n (%)			0.003
AG	3 (3.4)	4 (0.8)	
AL	0 (0.0)	18 (3.6)	
B1	30 (34.5)	248 (49.9)	
B2	25 (28.7)	127 (25.6)	
B3	12 (13.8)	40 (8.0)	
C	17 (19.5)	60 (12.1)	
AO/OTA type, n (%)			< 0.001
Oblique	8 (9.2)	77 (15.5)	
Transverse	24 (27.6)	24 (4.8)	
Wedge	7 (8.0)	17 (3.4)	
Spiral	45 (51.7)	307 (61.8)	
Metaphyseal split	0 (0.0)	50 (10.1)	
NC	3 (3.4)	22 (4.4)	

*Chi-squared test.
CB, composite beam; IQR, indicates interquartile range; N/A, not applicable; OTA, Orthopaedic Trauma Association; PTS, polished taper-slip; UCS, Unified Classification System.

fracture type between males and females (p overall < 0.010, chi-squared test, Table III). Males had a higher proportion of metaphyseal split (12.2% vs 5.4%) and oblique fractures (17.0% vs 12.4%) but fewer transverse (6.3% vs 9.9%), wedge (2.6% vs 5.4%), and spiral fractures (57.4% vs 62.7%) than females (p = 0.010, chi-squared test). AO/OTA fracture type differed between stem fixation philosophy groups (p overall < 0.001, chi-squared test, Table IV). CB stems were associated with a greater proportion of transverse (27.6% vs 4.8%) and wedge (8.0% vs 3.4%) fractures but fewer spiral (51.7% vs 61.8%) and oblique (9.2% vs 15.5%) fractures (p < 0.001, chi-squared test). Metaphyseal split fractures were seen in 10.1% of PPFs around PTS stems while none were seen with CB stems (p < 0.001, chi-squared test).

Effect of multiple variables on outcome measures: UCS grade. Fracture location was modelled as UCS grade with age, sex, and stem fixation as covariates, of which only sex reached statistical significance (Figure 1). The final model demonstrated that male sex was associated with an approximate five-fold reduction in odds of a C fracture (OR 0.22 (95% CI 0.12 to 0.41); p < 0.001, Wald statistic) compared to a B fracture.

AO/OTA fracture type. AO/OTA fracture type was modelled with age, gender, and stem fixation philosophy as covariates, of which stem fixation philosophy was the only variable to reach statistical significance (Figure 2). CB stems were associated with significantly increased odds of transverse fracture (OR 9.51 (95% CI 3.72 to 24.34); p < 0.001, Wald statistic) and significantly increased odds of wedge fracture (OR 3.72 (95% CI 1.16 to 11.95); p = 0.027, Wald statistic) compared to PTS stems.

Effect of fracture type on surgical treatment. Of the 584 PPFs in the series, 287 (49.1%) were treated with revision, 255 (43.7%) were treated with fixation, 38 (6.5%) were treated nonoperatively, two (0.3%) were treated with excision arthroplasty, and two (0.3%) were treated with above-knee amputation. Comparison was made between cases treated with revision and fixation (Table V).

UCS grade. UCS grade differed significantly between the revision and fixation groups (p overall < 0.001, chi-squared test). The revision group had more B2 (35.9% vs 17.3%) and B3 (13.2% vs 3.5%) fractures than the fixation group whereas the fixation group has more C fractures (26.3% vs 1.4%; p < 0.001, chi-squared test). A similar proportion of B1 fractures were seen between

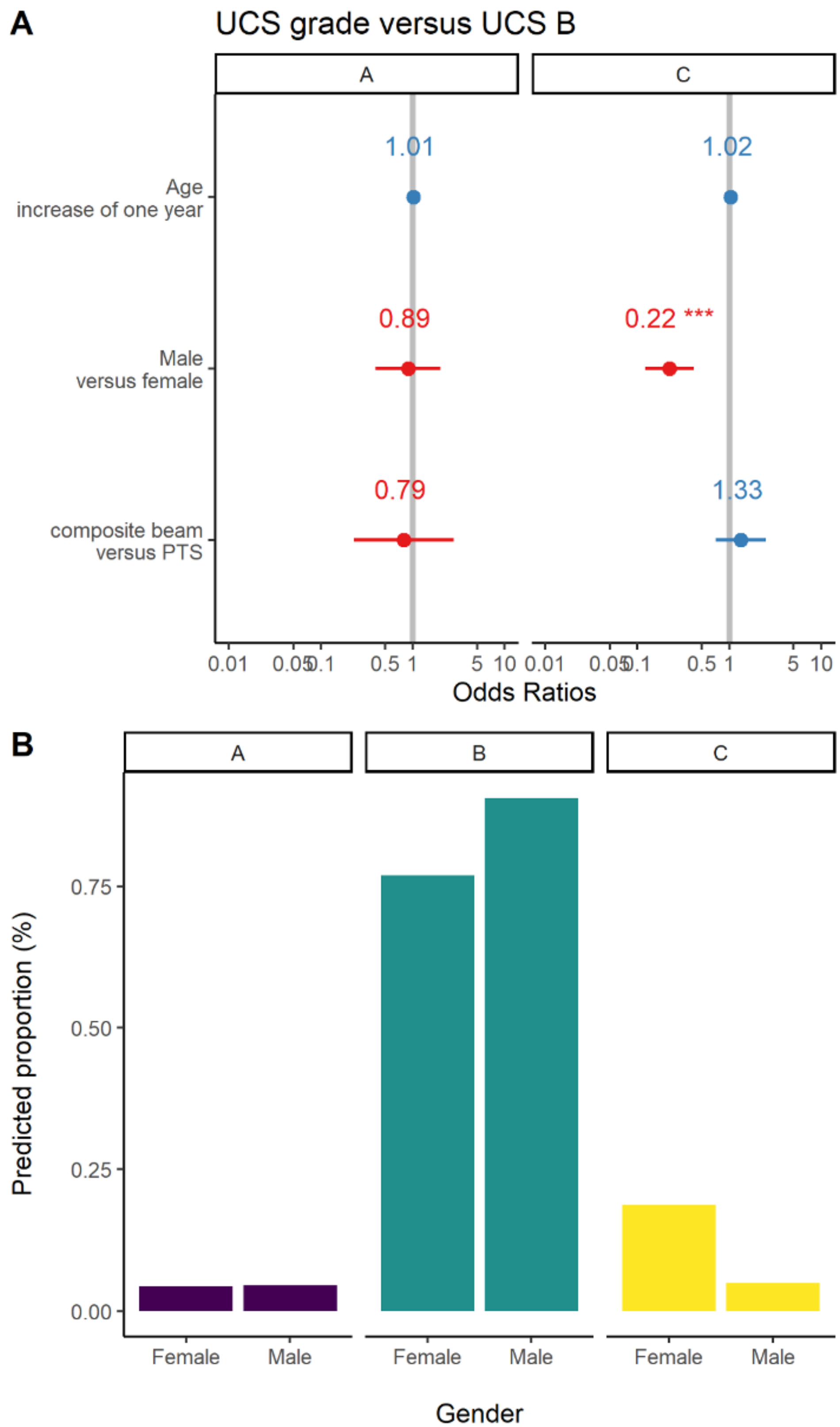

Fig. 1

a) Fixed effects of variables on Unified Classification System (UCS) grade (vs UCS grade B) from multivariate modelling of age, sex, and stem fixation philosophy and b) predicted values from fixed effects of sex on UCS grade. Note: *** indicates p < 0.001, fixed estimates indicated by dots, and numerical labels with 95% confidence intervals as adjoining whiskers, predicted values are for a 78-year-old patient with a polished taper-slip (PTS) stem.

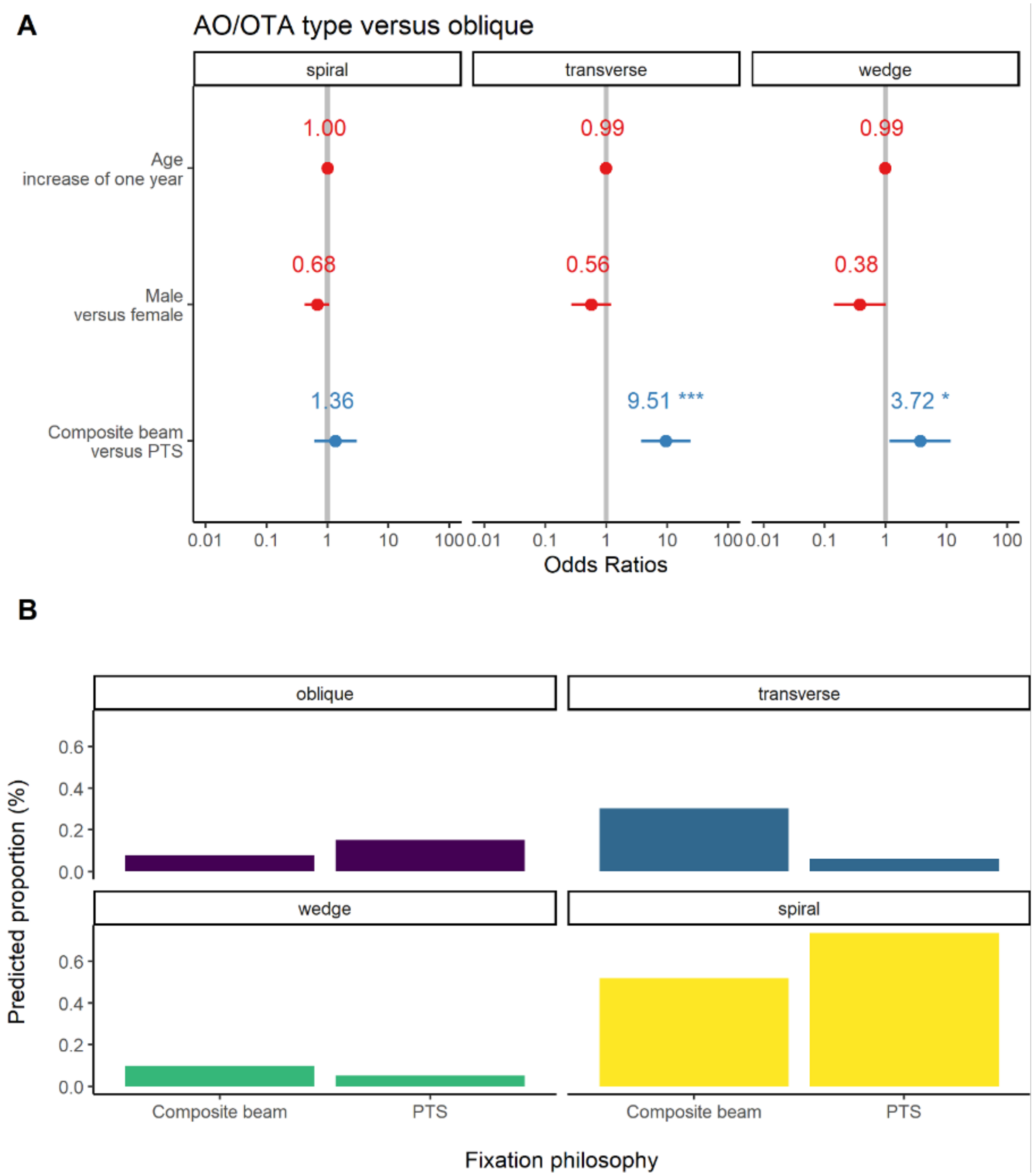

Fig. 2

a) Fixed estimates of AO/OTA type (vs AO/OTA oblique type) from multivariate modelling of age, sex, and stem fixation philosophy and b) predicted values from fixed effects of stem fixation philosophy on AO/OTA type. Note: *** indicates p < 0.001 and * indicates p < 0.05, fixed estimates indicated by dots and numerical labels with 95% confidence intervals as adjoining whiskers, predicted values are for a 78-year-old female patient. PTS, polished taper-slip.

the revision and fixation groups (45.3% vs 50.6%, respectively). A comparison of stem stable fractures (B1) versus stem unstable fractures (B2 and B3) also showed a significant difference between treatment groups ($p < 0.001$, chi-squared test; Table VI). The revision group had a similar proportion of stem stable and stem unstable fractures (48.0% vs 52.0%, respectively) but the fixation group had a much greater proportion of stem stable fractures compared to stem unstable fractures (70.9% vs 29.1%, respectively).

AO/OTA fracture type. AO/OTA type differed significantly between the revision and fixation groups (p overall = 0.001, chi-squared test, Table V). The revision group had a higher proportion of transverse (9.1% vs 5.9%) and

Table V. Comparison of United Classification System grade and AO/OTA fracture type by treatment method (revision vs fixation).

Variable	Revision (n = 287)	Fixation (n = 255)	p-value*
UCS grade, n (%)			< 0.001
AG	2 (0.7)	1 (0.4)	
AL	10 (3.5)	5 (2.0)	
B1	130 (45.3)	129 (50.6)	
B2	103 (35.9)	44 (17.3)	
B3	38 (13.2)	9 (3.5)	
C	4 (1.4)	67 (26.3)	
AO/OTA type, n (%)			0.001
Oblique	34 (11.8)	44 (17.3)	
Transverse	26 (9.1)	15 (5.9)	
Wedge	13 (4.5)	10 (3.9)	
Spiral	165 (57.5)	171 (67.1)	
Metaphyseal split	37 (12.9)	9 (3.5)	
NC	12 (4.2)	6 (2.4)	

*Chi-squared test.
CB, composite beam; IQR, interquartile range; N/A, not applicable; OTA, Orthopaedic Trauma Association; PTS, polished taper-slip; UCS, Unified Classification System.

Table VI. Comparison of Unified Classification System (UCS) grade and AO/OTA fracture type by treatment method for all UCS B and C fractures treated with either revision or fixation.

UCS, n (%)	Revision (n = 271)	Fixation (n = 182)	p-value*
B1 (stem stable)	130 (48.0)	129 (70.9)	< 0.001
B2 and B3 (stem unstable)	141 (52.0)	53 (29.1)	

*Chi-squared test.

metaphyseal split fractures (12.9% vs 3.5%) compared to the fixation group while the fixation group had a higher proportion of oblique fractures (17.3% vs 11.8%). Wedge fractures (4.5% vs 3.9%) and spiral fractures (57.5% vs 67.1%) had similar representation in both groups.

Discussion

This is the largest study investigating fracture characteristics for PFFs around cemented stems in THA. It shows that UCS grade is affected by sex while AO/OTA type is affected by stem fixation philosophy.

Age had no statistically significant effect on UCS grade. However, UCS grade does appear to be dependent on sex as males were five times less likely than females to sustain a type C fracture compared to a type B fracture. Type C fractures are effectively distal femur fragility fractures of which the majority are known to occur in female patients following low-energy trauma.[28,29] The presence of a cemented femoral stem does not appear to affect this association. The commonest UCS grade was type B1 for both PTS and CB stems. Univariate analysis demonstrated more type AG, B2, B3, and C fractures but fewer type AL and B1 fractures with CB stems compared to PTS stems. No type AL fractures occurred with CB stems in this series although the reason for this is unclear. By definition, PTS stems are not fixed at the stem-cement interface and normally subside within the cement mantle rather than at the bone-cement interface. In contrast, when subsidence occurs with CB stems, migration occurs at both these interfaces.[30] This explains why a greater proportion of type B1 fractures were seen with PTS stems and a greater proportion of type B2 and B3 fractures were seen with CB stems. The higher prevalence of type B2 and B3 fractures in CB stems can also be explained by the presence of osteolysis which is rarely seen with PTS stems.[31,32] More type AG and C fractures were seen with CB stems compared to PTS stems. These are more commonly seen with osteoporosis and this finding can be explained by an older and more female CB stem cohort.[33] Shape and surface finish differences are also likely contributing factors to the disparate distribution of UCS grade between stem types.[7] However, fixation philosophy did not affect UCS grade when other variables were accounted for during multivariate analysis.

Age did not have a statistically significant effect on AO/OTA fracture type but a difference in AO/OTA fracture type was seen with sex comparison during univariate analysis. Males had more metaphyseal split and oblique fractures but fewer transverse, wedge, and spiral fractures than females. However, sex was not found to be a significant factor during multivariate analysis. The most common AO/OTA type was spiral for both PTS and CB stems, which suggests a rotational mechanism of injury. CB stems had more transverse and wedge fractures but fewer spiral, oblique, and metaphyseal split fractures than PTS stems. The significant effect of stem fixation philosophy on AO/OTA type was confirmed during multivariate analysis. PTS stems were exclusively seen with metaphyseal split fractures but had reduced odds of transverse and wedge fractures compared to CB stems. This implies that AO/OTA type is dependent on stem fixation philosophy and is likely to be related to differences in stem geometry and loading mechanisms. Due to their wedge shape and smooth surface finish, PTS stems subside within the cement mantle for the first decade.[34] Axial loading, subsidence, and a wedge-shaped design render PTS stems more likely to result in metaphyseal split fractures than CB stems. In our series, these fractures occurred in 10.1% of PFFs with PTS stems while none occurred with CB stems. These complex fractures are considered typical of PFFs with PTS stems,[17,20] but this study confirms that their incidence is reassuringly low. Our results show that bending type fractures (transverse and wedge) were more common with CB stems and this likely relates to their loading properties. With CB stems, load bypasses the proximal femur, transmits to the stem tip and can lead to proximal stress shielding.[35] The subsequent stress riser at the stem tip may contribute to an increased susceptibility for bending type fractures. In contrast, PTS stems allow transmission of hoop stresses to the proximal femur and prevents stress shielding. Both metaphyseal split fractures and bending type fractures are inherently unstable fracture patterns. Although associated with higher complication rates, revision surgery is more likely to give better outcomes for these fractures than internal fixation due to the increased risks of nonunion and metalwork failure.[21-24]

Both UCS grade and AO/OTA type had a significant effect on surgical treatment. A greater proportion of B2 and B3 fractures with unstable stems were treated with revision surgery than fixation. This is an expected finding and is consistent with well-recognized treatment principles based on the original Vancouver classification of PFFs.[36] The same is true for C fractures where fixation remains the accepted standard of care. A small proportion of stem unstable fractures were treated with fixation which is may be an acceptable form of treatment for patients who are medically unfit for prolonged revision surgery. The most striking finding was that a similar proportion of B1 fractures were treated with revision surgery compared to fixation. This likely relates to the high prevalence of PFFs around PTS stems in this series and significant variation in practice in both classifying and managing these fractures. Equally successful results have been reported with both fixation and revision of PFFs around PTS stems, although it is accepted that the fracture and cement mantle must be anatomically reducible for fixation to be deemed an appropriate management strategy.[22,24,37] In addition to UCS grade, surgical decision-making is also likely to be multifactorial relating to training, local experience, availability of implants, and patient factors such as fitness for revision surgery. As might be expected, more transverse and metaphyseal split fractures were observed in the revision group as these are inherently unstable fracture patterns that benefit from revision surgery over internal fixation.[21-24]

This study provides clear implications for clinical practice. It provides new evidence that UCS grade is affected by sex while AO/OTA type is affected by stem fixation philosophy. It is the first to identify patient and implant related risk factors for PFF characteristics in cemented stems following THA based on validated fracture classification protocols and its findings should be incorporated into surgical decision-making regarding stem choice and the patient consent process. It is the first study to estimate the incidence of metaphyseal split fractures around PTS stems and offers reassurances that their incidence is low and therefore should not discourage the use of PTS stems. This study also highlights how traditional treatment algorithms may no longer be relevant to contemporary clinical practice,[36] and that consensus needs to be established for PFFs around modern cemented PTS stems, particularly B1 fractures. This should be supported by large comparative multicentre studies into clinical outcomes and cost-effectiveness. Our conclusions are strengthened by a large sample size and observational bias has been addressed by using a consecutive multicentre series of PFFs to enhances the external validity of our findings. We limited the confounding effects of heterogeneity by excluding hemiarthroplasty and interprosthetic fracture cases as the presence of a native acetabulum and/or a distal femur implant may affect PFF biomechanics. Further biomechanical testing is indicated to investigate our findings further with particular focus on improving axial and bending rigidity with variations in surgical technique.

We accept that this study has some limitations. There may be an element of sampling bias as there were more PTS than CB stems in the series. The UCS is based on the Vancouver classification of PFF and while this has been validated in previous studies on cementless and CB cemented stems,[38,39] it has never been reliably validated for PFFs around PTS stems. As there is currently no standardized definition for PTS stem loosening in the context of fracture, there may be inconsistencies in classification with interobserver differences. The time from stem implantation to fracture was not investigated. Though patients with PFFs associated with CB stems were older, we cannot comment as to whether the CB stems had been in situ for longer before fracture. We are also unable to determine the effects of BMI on fracture type due to incomplete data, but it is feasible that there is an as yet undefined association between raised BMI and unstable PFF patterns as has previously been identified in intertrochanteric hip fractures.[40] In addition, a clustering effect may have arisen due to the inclusion of high-volume specialist centres which may have led to a misrepresentation of some fracture types e.g. type AL fractures those that are often manged nonoperatively. While we were able to make observations about choice of treatment based on fracture type, we are unable to recommend a particular treatment as outcome data were not collected.

In conclusion, PFF characteristics around cemented femoral stems are associated with sex and stem fixation philosophy. These observations require biomechanical testing for validation and investigation of modifiable factors during primary THA which could reduce the risk of certain PFF patterns such as metaphyseal split fractures and bending type fractures. These complex fracture patterns usually require revision surgery which carries increased cost and morbidity compared to internal fixation.

Take home message

- Sex affects Unified Classification System grade, with more type C fractures seen in female patients.
- Metaphyseal split fractures are exclusive to polished taper stems but their incidence is reassuringly low (10.1%).
- Stem fixation philosophy affects AO/OTA type with more bending type fractures (transverse and wedge) seen with composite beam stems.
- A significant proportion of B1 fractures with stable stems undergo revision surgery, indicating a lack of consensus regarding optimal surgical treatment. Further biomechanical work is needed to address surgical technique during primary total hip arthroplasty which may reduce the risk of complex fracture patterns requiring revision surgery.
- Large comparative multicentre studies evaluating clinical outcomes and cost-effectiveness are required to determine the best treatment for periprosthetic femoral fractures around modern cemented stems.

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References

1. **No authors listed**. National joint registry 17th annual report 2020. https://reports.njrcentre.org.uk/Portals/0/PDFdownloads/NJR%2017th%20Annual%20Report%202020.pdf (date last accessed 15th November 2020).
2. **Wroblewski BM**, **Siney PD**, **Fleming PA**. Charnley low-frictional torque arthroplasty: follow-up for 30 to 40 years. *J Bone Joint Surg Br*. 2009;91-B(4):447–450.
3. **Petheram TG**, **Whitehouse SL**, **Kazi HA**, **et al**. The Exeter universal cemented femoral stem at 20 to 25 years: a report of 382 hips. *Bone Joint J*. 2016;98-B(11):1441–1449.
4. **Pennington M**, **Grieve R**, **Sekhon JS**, **Gregg P**, **Black N**, **van der Meulen JH**, **Cemented vanderMJH**. Cemented, cementless, and hybrid prostheses for total hip replacement: cost effectiveness analysis. *BMJ*. 2013;346:f1026.
5. **Westerman RW**, **Whitehouse SL**, **Hubble MJW**, **Timperley AJ**, **Howell JR**, **Wilson MJ**. The Exeter V40 cemented femoral component at a minimum 10-year follow-up. *Bone Joint J*. 2018;100-B(8):1002–1009.
6. **Purbach B**, **Kay PR**, **Siney PD**, **Fleming PA**, **Wroblewski BM**. The C-stem in clinical practice: fifteen-year follow-up of a triple-tapered polished cemented stem. *J Arthroplasty*. 2013;28(8):1367–1371.
7. **Thien TM**, **Chatziagorou G**, **Garellick G**, **Furnes O**, **Havelin LI**, **Makela K**. Periprosthetic femoral fracture within two years after total hip replacement: analysis of 437,629 operations in the Nordic arthroplasty register association database. *J Bone Joint Surg Am*. 2014;96-A(19):e167.
8. **Brodén C**, **Mukka S**, **Muren O**, **et al**. High risk of early periprosthetic fractures after primary hip arthroplasty in elderly patients using a cemented, tapered, polished stem. *Acta Orthop*. 2015;86(2):169–174.
9. **Palan J**, **Smith MC**, **Gregg P**, **et al**. The influence of cemented femoral stem choice on the incidence of revision for periprosthetic fracture after primary total hip arthroplasty: an analysis of national joint registry data. *Bone Joint J*. 2016;98-B(10):1347–1354.
10. **Carli AV**, **Negus JJ**, **Haddad FS**. Periprosthetic femoral fractures and trying to avoid them: what is the contribution of femoral component design to the increased risk of periprosthetic femoral fracture? *Bone Joint J*. 2017;99-B((1 Supple A)):50–59.
11. **Chatziagorou G**, **Lindahl H**, **Kärrholm J**. The design of the cemented stem influences the risk of Vancouver type B fractures, but not of type C: an analysis of 82,837 Lubinus SPII and Exeter polished stems. *Acta Orthop*. 2019;90(2):135–142.
12. **Mohammed J**, **Mukka S**, **Hedbeck C-J**, **Chammout G**, **Gordon M**, **Sköldenberg O**. Reduced periprosthetic fracture rate when changing from a tapered polished stem to an anatomical stem for cemented hip arthroplasty: an observational prospective cohort study with a follow-up of 2 years. *Acta Orthop*. 2019;90(5):427–432.
13. **Scott T**, **Salvatore A**, **Woo P**, **Lee Y-Y**, **Salvati EA**, **Gonzalez Della Valle A**. Polished, Collarless, tapered, Cemented stems for primary hip arthroplasty may exhibit high rate of periprosthetic fracture at short-term follow-up. *J Arthroplasty*. 2018;33(4):1120–1125.
14. **Gibbs VN**, **McCulloch RA**, **Dhiman P**, **et al**. Modifiable risk factors for mortality in revision total hip arthroplasty for periprosthetic fracture. *Bone Joint J*. 2020;102-B(5):580–585.
15. **Phillips JRA**, **Boulton C**, **Moran CG**, **Manktelow ARJ**. What is the financial cost of treating periprosthetic hip fractures? *Injury*. 2011;42(2):146–149.
16. **Lamb JN**, **Jain S**, **King SW**, **West RM**, **Pandit HG**. Risk Factors for Revision of Polished Taper-Slip Cemented Stems for Periprosthetic Femoral Fracture After Primary Total Hip Replacement: A Registry-Based Cohort Study from the National Joint Registry for England, Wales, Northern Ireland and the Isle of Man. *J Bone Joint Surg Am*. 2020;102-A(18):1600–1608.
17. **Fenelon C**, **Murphy EP**, **Baig MN**, **Kearns SR**, **Murphy CG**, **Curtin W**. Breaking bad: a comparative descriptive analysis of periprosthetic fractures around cemented and uncemented femoral stems. *J Arthroplasty*. 2019;34(8):1783–1786.
18. **Duncan CP**, **Haddad FS**. The unified classification system (UCS): improving our understanding of periprosthetic fractures. *Bone Joint J*. 2014;96-B(6):713–716.
19. **Meinberg EG**, **Agel J**, **Roberts CS**, **Karam MD**, **Kellam JF**. Fracture and dislocation classification Compendium—2018. *J Orthop Trauma*. 2018;32(1):S1–S10.
20. **Grammatopoulos G**, **Pandit H**, **Kambouroglou G**, **et al**. A unique peri-prosthetic fracture pattern in well fixed femoral stems with polished, tapered, collarless design of total hip replacement. *Injury*. 2011;42(11):1271–1276.
21. **Baum C**, **Leimbacher M**, **Kriechling P**, **Platz A**, **Cadosch D**. Treatment of periprosthetic femoral fractures Vancouver type B2: revision arthroplasty versus open reduction and internal fixation with locking compression plate. *Geriatr Orthop Surg Rehabil*. 2019;10(5):2151459319876859.10.1177/2151459319876859
22. **Smitham PJ**, **Carbone TA**, **Bolam SM**, **et al**. Vancouver B2 Peri-prosthetic fractures in cemented femoral implants can be treated with open reduction and internal fixation alone without revision. *J Arthroplasty*. 2019;34(7):1430–1434.
23. **Stoffel K**, **Blauth M**, **Joeris A**, **Blumenthal A**, **Rometsch E**. Fracture fixation versus revision arthroplasty in Vancouver type B2 and B3 periprosthetic femoral fractures: a systematic review. *Arch Orthop Trauma Surg*. 2020;140(10):1381–1394.
24. **Powell-Bowns MFR**, **Oag E**, **Ng N**, **Pandit H**, **et al**. Vancouver B periprosthetic fractures involving the Exeter cemented stem: Reducible fractures with intact bone-cement interfaces can be fixed. *Bone Joint J*. 103-B(2):309–320.
25. **Haddad FS**. Periprosthetic fractures: more challenges ahead. *Bone Joint J*. 2020;102-B(5):547–549.
26. **Quah C**, **Porteous M**, **Stephen A**. Principles of managing Vancouver type B periprosthetic fractures around cemented polished tapered femoral stems. *Eur J Orthop Surg Traumatol*. 2017;27:477:e82.
27. **Greenland S**, **Schwartzbaum JA**, **Finkle WD**. Problems due to small samples and sparse data in conditional logistic regression analysis. *Am J Epidemiol*. 2000;151(5):531–539.
28. **Martinet O**, **Cordey J**, **Harder Y**, **Maier A**, **Bühler M**, **Barraud GE**. The epidemiology of fractures of the distal femur. *Injury*. 2000;31(S1):62–94.
29. **Khan AM**, **Tang QO**, **Spicer D**. The epidemiology of adult distal femoral shaft fractures in a central London major trauma centre over five years. *Open Orthop J*. 2017;11(1):1277–1291.
30. **Alfaro-Adrián J**, **Gill HS**, **Murray DW**. Cement migration after THR. A comparison of charnley elite and exeter femoral stems using RSA. *J Bone Joint Surg Br*. 1999;81-B(1):130–134.
31. **Raut VV**, **Siney PD**, **Wroblewski BM**. Cemented Charnley revision arthroplasty for severe femoral osteolysis. *J Bone Joint Surg Br*. 1995;77-B(3):362–365.
32. **Lewthwaite SC**, **Squires B**, **Gie GA**, **Timperley AJ**, **Ling RSM**. The Exeter™ Universal Hip in Patients 50 Years or Younger at 10-17 Years' Followup. *Clin Orthop Relat Res*. 2008;466(2):324–331.
33. **Stevens J**, **Clement N**, **Nasserallah M**, **Millar M**, **Joseph S**. Femoral cortical thickness influences the pattern of proximal femoral periprosthetic fractures with a cemented stem. *Eur J Orthop Surg Traumatol*. 2018;28(4):659–665.
34. **Nieuwenhuijse MJ**, **Valstar ER**, **Kaptein BL**, **Nelissen RG**. The Exeter femoral stem continues to migrate during its first decade after implantation: 10-12 years of follow-up with radiostereometric analysis (RSA). *Acta Orthop*. 2012;83(2):129–134.
35. **Shen G**, **fixation Fstem**. An engineering interpretation of the long-term outcome of Charnley and Exeter stems. *J Bone Joint Surg Br*. 1998;80-B:754–756.
36. **Duncan CP**, **Masri BA**. Fractures of the femur after hip replacement. *Instr Course Lect*. 1995;44:293–304.
37. **Maggs JL**, **Swanton E**, **Whitehouse SL**, **et al**. B2 or not B2? that is the question: a review of periprosthetic fractures around cemented taper-slip femoral components. *Bone Joint J*. 2021;103-B(1):71–78.
38. **Brady OH**, **Garbuz DS**, **Masri BA**, **Duncan CP**. The reliability of validity of the Vancouver classification of femoral fractures after hip replacement. *J Arthroplasty*. 2000;15(1):59–62.
39. **Naqvi GA**, **Baig SA**, **Awan N**. Interobserver and intraobserver reliability and validity of the Vancouver classification system of periprosthetic femoral fractures after hip arthroplasty. *J Arthroplasty*. 2012;27(6):1047–1050.
40. **Irving D**, **Hinkley J**, **Marquart M**. The relationship between BMI and stability of Intertrochanteric fracture following low-energy falls. A retrospective cohort study. *Geriatr Orthop Surg Rehabil*. 2019;10(12):215145931985755.

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